

Pioneer Venus 1978 Mission Support: DLBI Wind Measurement Experiment End-to-End System Test Phase

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The ten months of end-to-end system checkout for the Differential Long Base Interferometry (DLBI) Wind Measurement Experiment for the Pioneer Venus Mission are described.

I. Introduction

The Pioneer Venus Multiprobe Entry on 9 December 1978 included as a major scientific objective the determination of the wind patterns as a function of altitude in the Venusian atmosphere. This experiment involved a ground-based interferometry experiment in order to measure the components of the wind perpendicular to the line-of-sight of each of the four Probes as they descended through the Venusian atmosphere. The execution of this experiment required coordination between four independent agencies:

- (1) The Massachusetts Institute of Technology (MIT), the home of the principal investigator, Dr. Charles C. Counselman III, and the location of the computer systems and software where the station and Probe to Bus differences are taken and the actual science executed.
- (2) Ames Research Center, the location of the Project Office.
- (3) Jet Propulsion Laboratory, which was assigned tracking and data acquisition management responsibility for the Pioneer Venus Project, responsible for the operation of the Deep Space Network, and assigned responsibility for overall coordination of the four tracking stations which supported the experiment.
- (4) Goddard Space Flight Center, responsible for the operation of the Spaceflight Tracking and Data Network and, in particular, for the operation of the Guam and Santiago sites used in the experiment.

Data flow for the experiment involves operation of receivers and recorders at four tracking sites around the Pacific basin (the DSN 64-meter stations located at Goldstone, California (DSS 14) and Tidbinbilla, Australia (DSS 43); and the 9-meter STDN stations located at Guam and Santiago, Chile) (see Fig. 1). The recordings made at the tracking stations are 12-megabit/second wideband digital recordings which have to be shipped to the Jet Propulsion Laboratory for preliminary processing. At the Jet Propulsion Laboratory, the 12-megabit/second recordings are processed to extract each signal of interest (for the mission seven signals: two cal tones, four Probes, and the Bus) individually onto reduced bandwidth computer compatible recordings. These computer compatible recordings are then shipped to MIT where the interferometric differences are taken and analyzed. It was clear from the outset that in order to determine that the total experiment was working properly it would be necessary to operate the entire end-to-end ground system, including equipment and software, at JPL and MIT. Since data from at least two stations were necessary in order to have an interferometer,

each test session would have to involve at least one overseas station. This meant that data tapes would have to be shipped from an overseas site to the Jet Propulsion Laboratory for processing; then the reduced bandwidth tapes would have to be shipped to MIT for further processing before the results can be known for any given test. It was then clear that upwards of a month could be expected between the time of taking test data at the stations and knowing the results of those tests. For this reason, it was planned from the outset to complete the implementation of the equipment necessary to support the experiment at the four tracking stations in February of 1978 to allow ten months to accumulate test data and trouble-shoot all elements of the system.

This report focuses on that ten-month test activity: the activities which took place, and the problems which were uncovered and solved.

II. DLBI Wind Measurement Experiment Prior to February 1978

The list of references at the end of this article gives background information about the experiment and the history of activities in support of the ground system portion of the experiment up to the February 1978 end-to-end system testing. Reference 1, from September 1975, describes the early identification of the DLBI Wind Measurement Experiment requirements and the assignment of the TDA responsibilities to the Jet Propulsion Laboratory when the decision was made that experimenter-provided equipment should not be used at the stations. Reference 2 gives a simplified tutorial as to the fundamental basis of the interferometric experiment and its basic requirements. Reference 3 defines the overall configuration at the four tracking stations and the bandwidth reduction equipment at the Jet Propulsion Laboratory when the basic design had solidified. Reference 4 describes the wideband digital recordings which were used at 12 megabits/second to support this experiment. Reference 5 describes the development of a special-purpose receiver for the support of the experiment. A portion of Ref. 6 describes the completion of the implementation and installation at the four tracking stations.

III. The Ten Months of End-to-End System Checkout

The magnitude of the test activity in retrospect is hard to believe; there were 20 test tracks executed using various combinations of the four tracking stations involved and well over three hundred 12-megabit/second tapes of data which were shipped from the tracking stations to JPL. A mechanism which developed in order to coordinate this rather extensive activity

was a teleconference between all supporting agencies on a periodic basis to report results and status and coordinate activity between the agencies. In an attempt to find some logical presentation of all this complex activity, the remainder of this report will give snapshots of the status during the 10-month period as reported at these teleconferences.

A. 26 May 1978

This first phone conference was held only between JPL and the Massachusetts Institute of Technology. This and each subsequent phone conference would always include engineering personnel on both sides of the interface as well as personnel responsible for tracking station operations. Since the technique (see Ref. 2) and the tracking station receiver and recording equipment were designed to accommodate a 2-MHz bandwidth, a complete test of the system was dependent on finding two usable signals that are contained within a 2-MHz bandwidth. From the onset it was planned to use various pairs of the ALSEPs (Apollo Lunar Surface Experiment Packages) on the moon as the signal sources for the test phase. Table 1 lists some of the key characteristics of the ALSEPs.

The first test track took place on 28 February and was to involve ALSEPs 2, 1, and 4, and DSS 14 and Santiago. DSS 14 (the DSN 64-m station at Goldstone, California) experienced considerable difficulties during this track due to a combination of equipment and procedural problems which were compounded by the fact that two of the three ALSEPs were malfunctioning. ALSEP 2 appeared to be blinking off and on and ALSEP 1 was apparently off. The next track was scheduled for 9 March and involved DSS 14, DSS 43 (the DSN 64-m station in Australia), and Guam. Guam tapes for this track were lost before being received at the DSN Network Information Control Center. (During the second week of November the tapes mysteriously turned up in the Network Information Control Center.) Over the course of the next several tracks, tape shipment times were very excessive, and it was decided that for the actual mission day all critical tapes should be handcarried from the four tracking stations. Also, after the first track, the tests switched to using ALSEPs 3 and 5, which were considered less desirable by the experimenter because historically neither ALSEP 3 nor 5 was as stable in frequency as ALSEP 1.

Because of the tape shipment time problems, by the 26 May teleconference MIT had only been able to process the DSS 14 and 43 data from 9 March. With some handwork, MIT was able to compute an interferometric phase but it had a noise level and structure which in no way met the requirements of the experiment. In addition, in processing of a single tone from a single station, there was a great deal of structure, some of it periodic, which should not have been expected if

everything had worked properly. Most of the early tracks had one problem or another generally due to procedural, logistic, or discrete failure. For example, initially the first tapes received from Guam were thought to be degaussed until it was discovered that the Guam tapes merely had not been rewound. Also, there were startup problems in the bandwidth reduction process at JPL where a lot of the initial data was delivered with improperly selected local oscillator functions for doing the bandwidth reduction. In this early phase, very few technical problems with the station equipment were uncovered. There were several errors in the bandwidth reduction software, which were uncovered using the information provided by the experimenter from the March 9 track.

B. 20 July 1978

Between the first and second teleconferences, coordination of problem solving was handled on an individual basis between the supporting agencies. For the 20 July conference, Goddard Space Flight Center was added to aid in coordinating the STDN support activities. At this teleconference, an apparently internal S-band RFI for Santiago track was discussed. MIT also reported further errors apparently made at JPL in selecting the local oscillator function for the bandwidth reduction. In addition, it was reported that the cal tone signal levels from DSS 43 were extremely weak and sometimes not detectable. This problem had been isolated prior to the teleconference to an S-band coupler in the antenna portion of the system, which had been installed backwards.

At this teleconference, the experimenter gave an extensive tutorial on how to use the Fast Fourier Transform output in the bandwidth reduction process to determine if the proper local oscillator function had been chosen. There was considerable discussion as to whether cal tone signal levels had been properly set up at 64-m stations in order to allow for the increases in noise temperature due to the moon. It was determined that mission values for the cal tones should be adequate if the system were operating properly. A new problem realized at this teleconference was that there were also cal tone problems at DSS 14 where the cal tones were significantly weaker than they should be and the upper cal tone was usually missing. By this time, indications were that all systems at the Guam station were fundamentally working properly, although the absolute phase stability of the system was poorer than expected, though tolerable. By now it was recognized that these phone conferences should be scheduled on a routine basis in order to coordinate all activities in the time remaining.

C. 10 August 1978

It was at this phone conference that MIT reported results from some test tracks which indicated for the first time that

this experiment might be able to work after all. Dr. Counselman reported the results from two tracks: one at DSS 43 and Guam and the other at DSSs 14 and 43, where the single difference was on the order of 1 to 4 parts in 10^{12} over 15 minutes (probably all attributable to differences in station frequency standards) and a double difference on the order of 0.03 degree (at S-band) per second over a 15-minute interval. Counselman felt at that time that a fair amount of the differential drift may have been attributable to an approximation used in the MIT processing improperly handling lunar librations.

The logistic problems of tape shipments were fairly well resolved by this time, although tape shipment times were still longer than desired. By now it was clear that JPL had learned how to properly handle the local oscillator function in the bandwidth reduction process. Cal tone problems were still evident for DSS 14. The basic signal level problem in the cal tones at DSS 14 had been solved by the discovery that the same coupler was installed backwards at DSS 14 as previously discovered at DSS 43. However, there were still new occurrences of the absence of the upper cal tone.

At about this time, the predict interfaces between the DSN and the STDN seemed to be fairly well worked out; however, a concern had been raised by the STDN about whether they could properly peak their antenna pointing during the actual mission event. Also, subsequent to the last telecon, ALSEP 5 apparently died and the test activity had to switch back to using ALSEPs 1 and 4. This introduced a new constraint that all test tracks be scheduled while the sun was shining on ALSEP 1 because this ALSEP package could not be revived in the dark.

At this teleconference a new problem was identified in that apparently the 12-megabit/second recordings occasionally suffered drop-outs in the servo reference track which caused observed time glitches in the MIT processing. An adjustment of the servo gain settings on all recorders decreased the problem significantly; however, time glitches still existed. It was expected that the time glitches would be minimized on 9 December by the use of more expensive certified tape for the actual mission. Some of the test tracks were now being processed using a linear "ramp" instead of a fixed frequency for the local oscillator function in the bandwidth reduction in order to reduce the bandwidth further and in order to start testing the proper operation and recovery of the data for a dynamic local oscillator function in both the JPL and MIT software.

D. 24 August 1978

One topic for this conference was whether the system noise increase due to the Planet Venus would be detectable at the STDN stations in order to determine that they were on point. It had been determined that the increase was not significant enough to be used for this purpose. The thought developing at that time was that the Orbiter spacecraft might be usable with the STDN spectrum analyzers to determine that the antennas were, indeed, on point. A major topic in this teleconference was the continued cal tone problems at DSS 14.

Also reported by Counselman was a track on 22 June involving all four stations where one of the two ALSEPs was undetectable in the DSS 14 data while that same ALSEP was a good strong signal from the other stations. This single occurrence of an apparent shrinkage in the bandwidth of the MMR (Multi-Mission Receiver, a DSN misnomer for the special 2-MHz bandwidth receiver built to support the experiment). This problem was never observed to recur and was never satisfactorily explained except possibly for the discovery some time after that track of a loose connection in a cable in the MMR.

An extensive test activity to isolate the cal tone problems at DSS 14 as of this teleconference had not been successful. The RFI at Santiago had been isolated to some work which had been taking place on the ranging system at the station. Also, high error rate problems were starting to show up on the DSS 43 12-megabit/second recordings.

At this point, it was decided that the absolute phase drift of 300 and some degrees over 2000 seconds for a single cal tone at the STDN stations observed by MIT was characteristic of the station equipment and not indicative of any problem, particularly since the more critical differential specification of 1 degree over 100 to 1000 seconds was, in general, being met. It was decided to schedule Pioneer 11 tracks for the STDN stations and the DSN stations since Pioneer 11 was currently at a signal level which approximated the expected signal levels during Multiprobe entry. In addition, the STDN had executed special tracks of the Pioneer Venus Orbiter in order to check out the antenna pointing, and this activity was to proceed for several months, resulting in the solving of all remaining antenna-pointing problems.

It was also decided at this teleconference to start sending the tapes from Santiago and Guam directly to JPL to save some of the shipping time. It was at this point in time when JPL was able to find the resources to develop a means of processing special 50-kHz space calibration tone data referred to as rail data. All stations were then requested in the future to take periodic 50-kHz rail data. Problems with the predict

interface to the bandwidth reduction were continuing to be pursued. It was decided that a backup form of manual predicts must be available in case the predicts interface problems could not be solved. Although in the months that followed the hardware predict interfaces were demonstrated to be working properly between the predict program and the bandwidth reduction process, the navigation to DSN predict interface in the last two weeks before entry failed to produce any usable post-entry predicts for the small Probes. This problem was never solved, and manually generated predicts were used both for station operations the day of entry and for the bandwidth reduction process that followed.

It was becoming clear that the ALSEP packages were no longer useful since ALSEP 1 had gone completely unstable. It was then discovered that the Voyager spacecraft was able to transmit 320-kHz subcarriers without data modulation and that, therefore, it represented a 3-signal source which might be usable for additional calibration of the experiment. At this teleconference, the experimenter reported that although the results to date were close to meeting the requirement (they missed by about a factor of 5), he still felt that much of the problem might be in the approximate handling of the lunar librations and also in oversensitivity to the short-term instability of the ALSEP signals in the MIT processing. It was anticipated that the switch from ALSEPs 3 and 5 to ALSEPs 1 and 4 should cause a factor of 10 degrees in the lunar libration problem which might confirm that MIT modeling was the major source of the drift in the differential phase. This is because of the shorter distance between ALSEPs 1 and 4 (see table).

E. 13 September 1978

The most recent test tracks were discussed. The first track of six was lost due to ALSEP 1 being off. In the second track, no signals were present in the DSS 14 data, apparently due to a loose cable in the MMR. In the third track, Station 14 suffered a maser failure and could not take any data, and predicts were inadvertently destroyed for DSS 43 prior to the track so that only Guam data could be taken. The Guam data looked good as far as could be told from a single station's data. The next track was the first Pioneer 11 track between DSS 43 and Guam in order to take data at realistic signal levels and a similar track for DSS 14 and Santiago took place. The first attempt at a Voyager track was made; however, data modulation was present on the subcarriers making the data unusable. The problem with DSS 14 cal tones had finally been solved by the discovery of a cracked hardline in an antenna portion of the calibration tone generation equipment.

A major activity underway at MIT in this time period was the debugging of the algorithm for processing the reduced

bandwidth data from JPL. This was a non-trivial debugging process which involved a significant amount of direct engineering interface between MIT and JPL. In order to preserve the phase information, a great deal of attention had to be paid to all buffer structures and update procedures within the bandwidth reduction software. The experimenter reported that the ALSEP 1 and 4 data did verify that lunar libration had been responsible for the majority of the remaining drift in the double difference. The result now was an average slope in the double difference for 1000 seconds of 0.01 degree per second, which corresponds to a velocity measurement error of about 4 centimeters per second. A 4-hour ALSEP track had been desired by MIT in order to get at the lunar libration problem. Due to a variety of problems, a 4-hour track was never successfully achieved, but because of the above results, MIT relaxed the requirement for such a track. It was decided that the remaining tracks should concentrate on realistic mission signal levels and Voyager due to the dying ALSEP packages.

F. 4 October 1978

Santiago and Guam could not detect the Pioneer 11 signal, which was at realistic Probe mission signal level. However, the Bus signal should still be detectable and make possible the use of the spectrum analyzers for end-to-end signal path continuity checking during the actual mission event. A second Voyager track with the spacecraft in the proper mode was successfully executed. Such a tremendous volume of data had been collected that an agreement was reached with MIT as to what data it would be useful to bandwidth-reduce and send on to MIT. Data analysis since the last teleconference confirmed that the cracked hardline was, indeed, the source of the cal tone problems at DSS 14. MIT also reported considerable progress in solving all of the interface problems with the bandwidth-reduced data and in particular the proper handling of dynamic LO functions. Some special test tapes were requested by the experimenter to further check the MIT processing.

A discrepancy in the observed signal level during the Voyager track was observed between Guam and Santiago.

Subsequent to this teleconference, a paramp problem was discovered and isolated at Santiago. Worsening quality of the 12-megabit/second recordings from DSS 43 was reported at this teleconference. At the last teleconference, MIT had reported the development of a software fix to step over the sync track timing glitch problems. It was now reported that this algorithm apparently did not handle all cases and that special processing techniques were requested in the bandwidth reduction in order to enable the software fix at MIT to function. With the limited time remaining, it was agreed by all parties that all future tracks should concentrate on tracking the Bus spacecraft (although this is known to not be a usable source

for the double difference interferometry) in order to get data at realistic mission signal levels and to continue to practice operating the equipment.

G. 18 October 1978

By the time of this conference, renewed tape shipment problems had delayed the arrival of the successful Voyager data at JPL. An extensive test activity was still continuing at DSS 14 at this time in order to verify the proper operation of the receiver and the cal tone generation system. It was reported that the DSS 43 noisy recording problems were most likely due to alignment and gain setting problems. A special calibration tape was sent to the station in order to execute a major realignment. It had also been observed that a general slight increase in "noise" level from all stations was occurring and a new head-cleaning procedure was being investigated involving chromium dioxide tapes. MIT reported further refinements in their data processing which had reduced the reported residual drift of the double differenced data from the best ALSEP 1 and 4 tracks from a 0.01 degree per second to 0.003 degree per second for 1000 seconds.

H. 8 November 1978

The strategy was now shaping up for the STDN stations to use the stronger Orbiter spacecraft signal (for peaking antenna pointing) and the Bus signal for validating signal path integrity through the receiver and recorder. The STDN also made known plans to have Goddard engineering personnel on site starting about one week before the Probe entry. The DSS 43 recorders were now believed to be operating satisfactorily except for one minor discrepancy which was not mission critical: DSS 43 could record on Recorder A and play back on A or B, and record on Recorder B and play back on B, but they could not record on Recorder B and play back on A.

A growing concern was raised over phase jumps which had been experienced, particularly in some of the DSS 14 data. These phase jumps seemed to have a characteristic of being a multiple of 120 degrees. DSN engineering personnel spent many test hours at Station 14 but were unable to detect any such phase jumps. However, processing of 50-kHz rail data at JPL did uncover the existence of phase jumps. After this teleconference, it was discovered that the divider in the calibration tone generator (which was selectable from a divide by one to a divide by 99) was marginal and could under certain conditions occasionally divide by n plus one instead of n . This device is used in a divide by three mode in the actual mission and a divide by 99 to generate the 50-kHz rail data. All testing done at Station 14 to try to isolate the phase jumps was executed assuming the problem was in the receiver and calibration signals were generated outside of the calibrator. In addition, rail data from Santiago could only be processed by

assuming divide by 100. This seemed to explain the problem and indicated that it was a potential problem at all four stations.

MIT reported that they had all bugs out of their processing with respect to interfacing with the Bandwidth Reduction Assembly and properly handling dynamic local oscillator functions. In processing the same data with a fixed LO and with ramping, MIT was able to achieve agreement to within 0.01 degree for a thousand seconds. The bad news was that MIT was unable to detect the Pioneer 11 data taken by Santiago, which was supposed to be realistic Probe mission signal level. MIT was able to detect the Voyager data from Santiago. At an STDN station the Pioneer 11 data was approximately -176.5 dBm while the Voyager data was -164 dBm.

I. 22 November 1978

The STDN was having difficulty tracking the Bus because of inaccurate trajectory data. A decision was made to provide daily state vectors from JPL to Goddard so that the long-term integration of the trajectory would be done by the JPL program and concern over compatibility in trajectory modeling between Goddard and JPL could be eliminated. It was also reported at this time that apparently the Goddard predicts did not take account of one-way light time (which, of course, is not necessary for satellite tracking), which accounted for some of the previous biases experienced in antenna pointing. During one test track, Pioneer Project was requested in real-time to change from high to low mod index for the Bus spacecraft telemetry, which gave a 6-dB gain in signal-to-noise ratio for detection of the carrier at STDN stations. It had been the mission plan for some time to use the low mod index on the Bus until the Probe entries were complete so that the STDN stations would have a stronger signal for system validation. From the recent test data, it was now felt that the Bus would be a usable signal instead of the Orbiter for antenna peaking as well as verifying signal path integrity.

An additional concern was brought up when Dr. Counselman reported that from the four-station Voyager track he was able to detect the Voyager signal on every station's data except Santiago. MIT was also having difficulty with the Voyager data due to inaccuracies in handling the Voyager trajectory. A fix had been found for the divide by n plus one problem in adjusting a pot built into the system at all four stations. In the process of adjusting this pot at Santiago, a wiring error was discovered which caused the divider to divide by 100 specifically when the switch was in the 99 position. This explained the previous problems observed in the 50-kHz rail data from Santiago. No further n plus one problems were seen from Station 14 subsequent to the adjustments made for the mixer. Unfortunately, the independent cause of the divide

by 100 at AGO gave less confidence that the n plus one problem was really solved so continued taking of the rail data at DSS 14 would take place until entry to gain confidence that the problem had been solved.

Counselman reported that data from all four stations in recent tracks had many more time glitches than in previous data. From the discussion during the teleconference, it was realized that the DSN in troubleshooting the noise problems with the DSS 43 tapes had changed the settings in the CTA-21 recorder. The CTA-21 recorders were adjusted back to spec subsequent to the teleconference and all future recordings had a more acceptable number of time glitches.

J. 30 November 1978

MIT reported that all was well with Santiago because on re-examining the Voyager data they could now detect the signal and, indeed, detect the even weaker Pioneer 11 signal. MIT had also uncovered some errors in their handling of the Voyager trajectory data, and work was continuing to get the useful content out of the Voyager track. The most urgent problem revealed in this teleconference was that more recent Santiago data had showed a very high noise level with significant phase jumps and an excessively high absolute rate of drift. After an extensive discussion on this issue, several people seemed to focus on the problem probably being in the synthesizer used in the rail generation. Part of the symptoms of the Santiago problem was the presence of 60-Hz spikes on either side of the cal tones. It was also decided that one last teleconference on 6 December would be prudent.

K. 6 December 1978

Once the problem from the last teleconference was identified to Santiago, the station was able to see the 60-Hz noise using their own spectrum analyzer and was quickly able to isolate the problem to a change from a 5-MHz reference to a 1-MHz with a multiple by 5 that somehow slipped by during a major reconfiguration that took place at the station independent of the DLBI support.

The general consensus was that the experiment was as ready as it could be, that readiness had plateaued, and that most recent problems were random equipment failures.

L. The Final Week

In the final week and one-half before the Probe entry, the following discrete failures occurred: DSS 43, coincident with making adjustments to get at the divide by n plus one problem, lost approximately 8-dB gain in the receiver. This problem was traced to a failed mixer for which there was a spare on site. Since it was undesirable to go into the short hours of

9 December without a spare, the failed mixer from DSS 43 was shipped to JPL for repair and the spare mixer from DSS 14 shipped to DSS 43. The spare mixer was repaired at JPL and sent out to DSS 14 before 9 December. Guam experienced a cesium failure, apparently just due to the age of the particular cesium tube, but was able to switch the backup cesium on-line and maintain time due to the availability of a good quality LORAN-C source. Station 14 experienced a complete failure in a commercial part of one of the Spectral Signal Indicators just four days before entry. A JPL engineer removed the device from DSS 14 and flew it to the vendor in San Diego and had a repaired one back, installed and operating at the station two days later.

IV. Summary

At the time of writing, all indications in the post-entry processing to date are that the DLBI Experiment equipment operated near perfectly on 9 December. First results from

processing just the calibration signal for the 64-meter stations are a differential phase difference of less than one degree at S-band for 10,000 seconds with the absolute phase of a single cal tone having a variation of less than 20 degrees over 5000 seconds. For the STDN stations, at the time of writing, the preliminary results are less than one degree of differential phase error in 2000 seconds with an absolute phase of a single cal tone variation of about 300 degrees. The latter appears to consist mostly of a linear drift with only about 10 degrees deviation from linear for the 2000 seconds.

The above, of course, does not yet verify that the experiment worked and met the accuracy objectives; however, it is a preliminary indication that the receiving and recording equipment at the stations were operating as well as or better than they operated in any of the ten months of end-to-end system checkout. By the time of the next issue of the DSN Progress Report, more conclusive indications of performance should be available.

References

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Table 1. ALSEP characteristics

Frequency (MHz)	2275.5	2276.0	2278.0	2278.5	2279.5
ALSEP number	5	3	2	1	4
Apollo Mission	17	16	15	12	14
ALSEP location	30.8E 20.8N	15.5E 8.9S	3.6E 21.1N	23.4W 3.5S	17.5W 3.6S

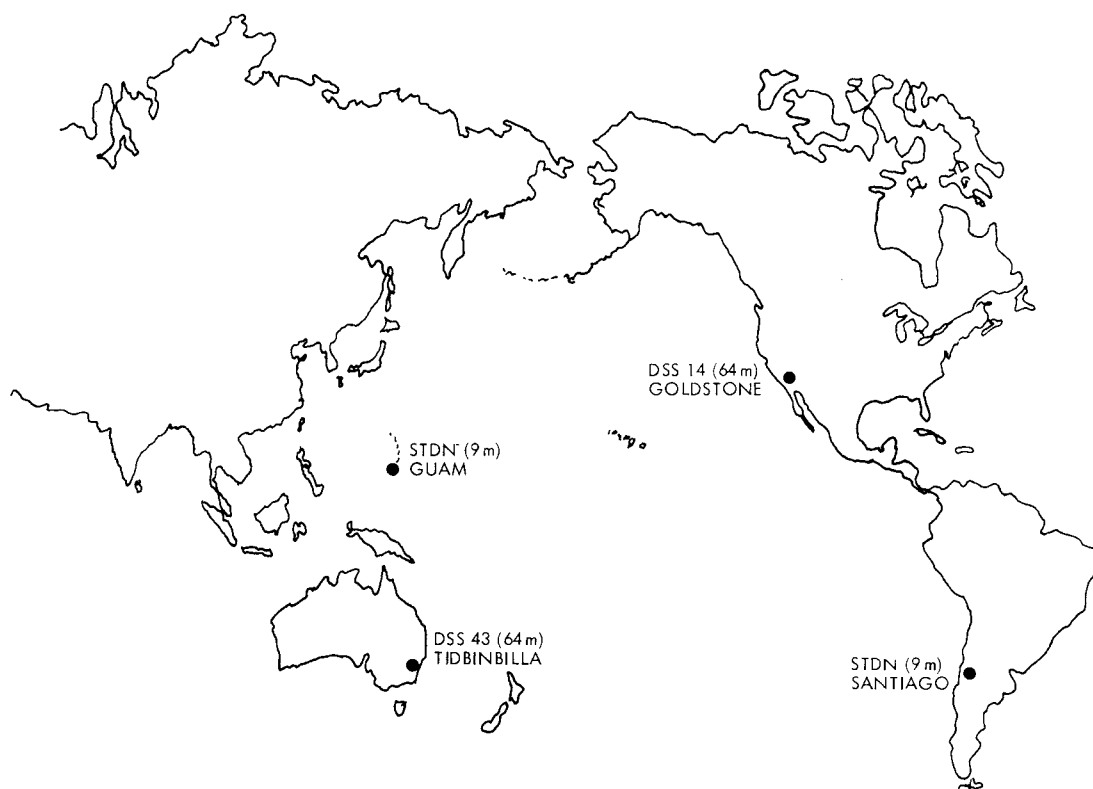


Fig. 1. DSN and STDN station locations, DLBI Wind Measurement Experiment